

FLORISTIC DOCUMENTATION IMPERATIVES: SOME CONCLUSIONS FROM CONTEMPORARY SURVEYS IN PAPUA NEW GUINEA

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ABSTRACT

In recent years, Papuan surveys patterned on rapid-assessment formats have become increasingly popular for developing floristic estimates of site value. Although some of the results have been widely disseminated, there have been few attempts at overall synthesis despite the obvious need for such review. A commentary on botanical exploration and documentation during the past decade is provided, with particular focus on connections between current conditions and the fulfillment of goals implicit in comprehensive bioinventory.

TOK IGO PAS (MELANESIAN TOK PISIN)

Long nau tasol, ibin igat luksave na wok painim aut ibin kamap planti moa long ol bus na diwai bilong Papuasia. Maski ibin igat sampela save bilong wok painim aut istap na ibin kamap long planti hap nabaut, ibin igat wok traime tasol i kamap long dispela wok bilong painim haumas bus na diwai istap long Papuasia. Dispela em i ripot o toksave long ol wok painim aut wei ikamap long ten pela yia igo pinis na luksave long wok ibai kamap bihain taim long wei bilong painim aut ol diwai na bus.

ABSTRACT

近年、植物学的見地からの地域の重要性を評価するための方法として、ラピッドアセスメント方式によって行なわれるパプアシア調査が増加しており、幾つかの科学的調査結果が広く発表されている。これらの研究の総括が、将来の研究の発展に必要な指針となることは明らかであるにもかかわらず、そのための努力は怠られてきた。本論文では、現在の研究方法で本来我々が求めている成果を本当にあげられているかどうかの検証に焦点を当てながら、過去10年間の植物調査と発表論文に関する論評を行なう。

INTRODUCTION

In spite of its status as a global center for biotic diversification, Papua New Guinea (PNG) has the dubious distinction of being one of Malesia's most inadequately surveyed nations. Stevens (1989) had defined the relatively well-collected areas in PNG as having a collections density of 50–100 specimens per 100 sq km. But

even by this easy measure, the well-collected localities identified by his criterion were primarily confined to a few principal drainages and high mountains. Recent analysis shows that the background level of collection density averages less than 25 per 100 sq km over New Guinea as a whole (Conn 1994), a rate substantially below the standard regarded by Stevens as a minimal baseline. Within the Malesian region, only the Celebes and Sumatra have comparably low collection indices (Stevens 1989). Although Steenis (1950) had estimated that 50 years of coordinated exploration would be required to document the New Guinea flora, the rate of documentation has not improved since that assessment was made, and has in fact dramatically declined within the last 30 years (cf. Conn 1994). If rational conservation strategies and land-use policies are to be devised and implemented by indigenous agencies, the present trends in documentation must be reversed. The urgency for corrective action is especially acute when the target country represents a biodiversity hotspot within which social and economic changes are expected to intensify.

Papua New Guinea's population growth rate of 2.3% is now one of the highest in the Pacific region. From a present base of 4.7–5.0 million, the number of people is expected to double by 2024 (Gumoi & Sekhran 1995). The demographic projections are especially consequential because an estimated 84% of the population is rural, and all such households are dependent to some degree on slash and burn agriculture (*ibid*). Currently, an estimated 200,000 hectares of land are cleared annually for subsistence, from which 20,000–30,000 hectares represent natural-growth forest permanently removed by various clear-cut operations including industrial logging (Filer 1995).

With the anticipated increases in human population, subsistence activities are expected to progressively mimic the effects of forest clear-felling as fallow cycles are accelerated (Louman & Nicholls 1995). When PNG enters the steep part of the predicted population growth curve, serious environmental impacts are likely to occur. There are already mounting indications of impending failure in the subsistence systems of several provincial areas due to intensification of cropping rotations (Levett & Bala 1995).

At present, PNG still retains 70% of its primary forest cover (McAlpine & Quigley 1998) and is one of only four tropical countries with extensive tracts of original vegetation (Suzuki 1993). This remarkable state of preservation has unfortunately fostered a complacency among science professionals by encouraging an expectation that current inadequacies in documentation can always be reversed by future action. The underlying assumptions are not likely to persist however. Time will start running out sometime during the next generation.

The poor state of floristic documentation has many and significant manifestations in Papuasian botany. A disproportionate number of taxa are known from single collections, and taxonomic knowledge even at family level is often highly superficial (Johns 1993). Virtually nothing can be said of the basic biology

and populational variation for many of the most important Papuan plant groups (Stevens 1989). While it is generally conceded that certain mountainous areas are hotspots for floristic endemism, it is impossible to identify low-elevation centers with the scanty data at hand. Some consequences of the past emphasis on high elevation exploration can be seen in recent results from The Nature Conservancy's lowland survey of Josephstaal, where 8 species were newly described from accessible sites near the principal national highway in Madang Province (Huynh 2000; Takeuchi 2000a, 2001). Lowland environments are preferred venues for economic development, so there is considerable potential for floristic losses in this zone. Continued neglect of botanical documentation in lowland habitats can have severe consequences in any future intensification of commercial logging, considering that over 50% of PNG's loggable forests (as defined by industry standards) are in the lowlands (Louman & Nicholls 1995). Of the forest blocks currently representing merchantable stands, 67% also occur in medium-crowned lowland hill forest (*sensu* Pajmians 1975; or forest category Hm on Hammermaster & Saunders 1995), a vegetation type which is probably Papua's richest floristic formation (Louman & Nicholls 1995).

Several competent observers have enumerated localities of particular value and urgency for exploratory survey within PNG (Johns 1993; Steenis 1950; Stevens 1989). A common thread extending through all these recommendations is that the exploration status of highlighted areas has hardly improved since the time of the Steenis commentary. Very little has changed with respect to the quantity and quality of botanical data over the past several decades. The lack of substantive progress adversely affects taxonomic and ecological assessments, and ultimately impedes sustainable management and development within the areas in question.

SOCIAL AND INFRASTRUCTURAL CONSIDERATIONS

In PNG, any activity requiring access to natural resources must include consideration of the traditional land tenure system. An estimated 97% of the country is under customary ownership, subject to complex systems of usage rights and social relationships which are themselves superimposed over a multitude of cultural-linguistic traditions (Crocombe 1974; Holzknecht 1995). Alienated land and properties otherwise under governmental control are virtually nonexistent. Irrespective of endorsements from external agencies, the final arbiters in land-use issues are the village clans and landowners of specific forest blocks (i.e., the 'papa graun').

Because so many prerogatives reside with local villagers, direct negotiations with the customary tenants are mandatory for any scientific program. This is not so easily done when an investigation's principals are overseas-based. Due to the proliferation of advocacy groups with environmentalist agendas, many landowners have also become conditioned to regard extractive activities on their

land (particularly by foreigners) with considerable suspicion. This situation applies especially to bioprospecting. Survey operators do well to avoid prospective collecting altogether, because of objections that have been raised in relation to such activities. Any contemplated project would be required to explain its activities to an oftentimes skeptical and uninformed audience. Having a functional knowledge of the lingua franca (Melanesian tok pisin) is essential.

A significant consequence of the primacy of customary rights in Papuasias is that certain Western mechanisms for permit issuance and resource access are culturally irrelevant in PNG. There is for example, no such requirement as a 'plant collecting permit.' Even if such permits were established by government agencies, they could never be enforced at the local level where botanical collecting actually occurs. Only the customary landowners can grant approval for removal of materials from their territory. Paradoxically, while this eliminates much of the bureaucracy characteristic of Eurocentric management systems, survey operations are often rendered more complicated and unpredictable, because the activities are entirely subject to the whims of individual landowners.

Modern commentators have been unanimous in expressing a need for developing local capacity as a prerequisite for longterm assessment and management of PNG's biodiversity (Beehler 1993; Conn 1994; Damas 1998; Johns 1993; Sekhran & Miller 1995). Public sector agencies in PNG are subject to unpredictable changes in government support due to shifts in political direction. Based on previous trends, it is very unlikely that vital commitments to science capacity building will occur through in-country funding. Collaborative studies are a potentially effective means for improving internal capabilities when appropriate agencies are engaged as partners in research. Programs which provide for participation of qualified counterparts can make longterm contributions to bioinventory, but the partnerships must be carefully selected and not merely convenient.

The PNG infrastructure in science has experienced profound changes over the last thirty years. During the colonial administration and for a brief time afterwards, many of the functions associated with floristic survey were centrally invested in highly capable units such as Lae Herbarium (LAE) and the former Department of Forests. Government facilities in the 1960s and early 70s virtually monopolized plant exploration within PNG. In contrast, nongovernment organizations (NGOs) were conspicuous by their overall absence from activities involving botanical documentation. However after PNG became a sovereign state, the capabilities of national agencies for floristic work progressively declined as budgets were subjected to a political reordering of priorities (cf. Conn 1994). The earlier priorities are unlikely to be restored in the future because institutional and social realities have been so completely transformed. For example, there are now no Ph.D.-level professionals in the PNG National Forest Service, and currently only one M.Sc. recipient is serving with the national herbarium.

To some extent, these trends in agency capabilities have been mitigated within

the last 10 years by countervailing developments in the nongovernmental sector. A seminal event was the Conservation Needs Assessment (CNA, Beehler 1993), the first countrywide plan to define comprehensive priorities for conservation and research action. The CNA stimulated establishment of a multitude of Wildlife Management Areas (WMAs) and of associated projects based on the Integrated Conservation and Development (ICAD) model (cf. Saulei & Ellis 1998). Not coincidentally, many of the post-CNA initiatives encompass at least in part, the areas prioritized by the CNA. Together with these developments, a number of NGO entities have assumed effective jurisdiction over the WMAs and their land-owner groups. Many of PNG's prime wilderness environments are presently included under NGO/Management Area partnerships. The total biodiversity represented by such partnerships is very substantial even though the arrangements collectively comprise only ca. 8% of the PNG land area. In addition, a large backlog of sites is under consideration for future conservation action.

The combined effect of these events is that the hierarchy of PNG science-related administration has been transformed by the creation of a new infrastructure. Due to the relative recency of the new arrangements, there has been little change in the way biological surveys are conducted in PNG. However nearly all the WMA-related NGOs maintain a fulltime presence within their respective wards, so the opportunities for achieving effective community integration with surveys are now very promising. The WMAs typically include resident-coordinators and protocols for maintaining continuous liaison with landowner groups, critical functions that government interests can no longer provide in the remote areas. From an operational perspective, each of the NGO/WMA combinations is the equivalent of a research facility. The elements for multilateral surveys combining professional and village participants are thus in place, requiring only that the individual components be drawn together under a common plan. A future schedule for comprehensive bioinventories could be constructed using the government planning instruments on one hand and community level implementors composed of WMA/NGOs on the other. Linkages of this sort are already the basis for several contemplated operations.

PARATAXONOMIST ENHANCEMENT OF SURVEYS

The sheer numbers of species involved in documentation and inventory are overwhelming when approached from traditional perspectives in collection and curation. Time honored traditions in tropical exploration are no longer adequate to the tasks of acquiring and analyzing large collection sets. A revised approach to floristic documentation is clearly required, and is perhaps best adapted from the experiences of entomologists faced with problems similar to those in botanical inventory.

Through refinement of comparable methodologies first developed by INBio in Costa Rica (Janzen et al. 1993), PNG-based researchers at the Parataxonomy

Training Center (PTC) have devised practical solutions to the time demands presented by intensive sampling in rich tropical habitats (Basset et al. 2000; Novotny et al. 1997). Their approach has been to train local villagers (as parataxonomists) in the fundamentals of collecting, specimen sorting, identification, and computer-based data management. The few international professionals are primarily engaged as instructors, quality control agents, and ultimately as data interpreters. By focusing the intervention of individuals to the points where their expertise is most effective, the research process is thus streamlined and accelerated. The immediate product of these arrangements is that extensive specimen sets have been acquired and processed within time frames that would ordinarily require prohibitive inputs. The demonstrated success of such organization in entomology by itself shows that the protocols can work for botany. Insects after all, exceed the floristic diversity by several orders of magnitude.

As an example of the enhancements offered by the new procedures, within a period of 5 years the PTC studies in insect herbivory have collected, sorted, and mounted over 100,000 specimens of leaf-chewing and sap-sucking insects representing ca. 1,300 species (cf. Basset et al. 2000; Novotny et al. 1997). Such outputs considerably exceed those obtained by conventional efforts without parataxonomist assistance. Over 40 scholarly papers have been published by the research team, in stark contrast to the normal downtime between study inception and publication (usually 4.6 years) for the kind of eco-entomological inquiry being undertaken by PTC researchers (Erwin 1995). These improvements are a direct result of the use of parataxonomists in time-intensive actions such as collecting and sorting, allowing other participants to optimize their own activities on cost-effective schedules. With the marked increases in sampling outputs, new insights have emerged which could only have arisen from statistically large datasets, such as are now being generated by the new protocols. The PTC sampling program has led to a reevaluation of insect-plant relationships, with wide-ranging implications for understanding the components of invertebrate diversity in tropical systems (Basset et al. 2000; Novotny et al. 1997). In an analogous manner, quantitatively boosted floristic surveys have the promise of spawning comparable advances in our knowledge of the taxonomy and ecology of the Papuasian/Malesian flora. This is especially likely when the existing sampling coverage for plants is so erratic and sparse.

A significant factor in the success of the PTC operation is the fact that instructors and students share fulltime residence in a combined laboratory-dormitory complex while pursuing common research objectives. Continuous interactions between mentor-trainers and parataxonomists instill a sense of fraternity and purpose which is not easily replicated by conventional projects, even though the latter may otherwise superficially mimic the PTC program structure and objectives. Preservation of the social relationships will be crucial to effective transference of the parataxonomist concept to floristic survey. Similar patterns

for success were previously pioneered at the Christensen Research Institute (Orsak 1993) and more recently by the Village Development Trust. Botanical planners should note the methodological paradigms, particularly the conditions contributing to their effectiveness, as the implications for floristic survey are both timely and considerable.

A point worth repeating is that the parataxonomist concept has been thus far applied primarily by entomologists. Unfortunately the botanical profession has been slow to recognize that many problems of biological sampling in the tropics are universal, and applicability of successful techniques is likely to cut across disciplinary lines. Especially with traditional cultures such as PNG, folk knowledge of plants is often more extensive than the corresponding base for insects (Basset et al. 2000) so plants are actually very appropriate subjects for parataxonomist-assisted investigation (Novotny pers. comm.).

If comprehensive parataxonomy programs are attempted within PNG, complementary improvements will be required in the facilities associated with biological documentation. Development of local capacities for floristic survey is unlikely to achieve lasting results if the physical security of collections (and other survey products such as databases) cannot be assured inside the host country. This can be a problem in developing societies where funding priorities for science are generally low. A permanent institutional base will also be needed, and is best achieved through the development of organizations specifically devoted to parataxonomy, rather than by placing parataxonomists in preexisting herbaria or government institutions. With scientific facilities in the public domain, there is likely to be an administrative bias favoring professional staff over individuals without formal credentials. The continuity of parataxonomists in such environments would be less secure than in a mission-specific unit such as PTC.

Steenis's estimate of a 50-year cycle of coordinated exploration is operationally impossible. In its reliance on outdated concepts of how such inventories should be achieved, it is also incompatible with the social realities of contemporary Papuasia. Existing funding facilities are unlikely to support such extended programs of deferred realization anyway. As long as limiting factors devolve exclusively upon a small number of highly trained professionals, whether indigenous or foreign, it is doubtful that real progress will be made toward the goals implicit in comprehensive survey. Only by significant expansion of the workforce, like that afforded by parataxonomy, will the inventory process be able to encompass the diversity within Papuan forest ecosystems. Methodologies which improve existing rates of floristic documentation are especially urgent in view of the habitat destruction which has occurred in Malesia since the time of van Steenis (cf. *inter alios* Kiew 1990).

Future surveys should include teams composed of purpose-trained parataxonomists. Participation by landowners will also permit outputs to be amplified across the board, resulting in survey yields substantially higher than

conventional expeditions. A collateral advantage of community involvement is the associated opportunity for integrating traditional knowledge systems into the collections documentation. Ethnobotanical inquiry can be easily assimilated when local inhabitants are engaged in surveys.

Although there is clearly a general failure of floristic documentation in Papuasia, little attention has been explicitly devoted to the way field operations are actually conducted. Yet that should be the logical starting point in any analysis, because how collections are acquired and the limitations associated with their acquisition, cannot help but affect everything else which follows. In any such examination, probably the most obvious limiting factor which would emerge is the ineffectiveness of existing collecting methods.

In the early days of the PNG Forest Service, rifle fire was often used to bring down fertile branches from the canopy. Nowadays, in a country where high-powered firearms require special permits, this is no longer a viable option for a number of reasons, not least of which being that possession of such weapons would attract undesirable attention to the collecting teams. In order to obtain specimens from high canopies, local climbers are thus employed on nearly all surveys. Selected trees are also frequently cut down. Both methods are very time consuming however, and it is not unusual for a single collection obtained by such means to take a half hour or even longer. Other procedures using slingshots, extensible poles, wire saws, etc. are useful only in certain situations, and also require a substantial amount of practice before the field assistants can achieve reasonable proficiency.

The search for suitable gatherings is often lengthy just in itself. Especially in mature growth, where the forest biomass and collection targets are located far above the ground, few taxa will be within easy reach. Under prevailing conditions, a collector with several assistants can expect to obtain an average of only 30 taxa per day. Daily tallies tend to be higher in regrowth and montane vegetation because of their lower statures, but generally a botanist will not take more than 50 numbers even under favorable circumstances. Add to these considerations the fact that collectors in logistically difficult environments are often burdened by institutional quotas for multiple duplicates, and the time/cost demands are increased even further.

Efforts diverted to the preparation of duplicate samples detract from the documentation process. The international herbaria with significant traditions in Papuan botany are few in number, so a point of diminishing returns is quickly reached when distributing specimens. Collections consisting of numerous duplicates are very inefficient in terms of the costs in obtaining those duplicates. Floristic inventory is better served by securing small sets (3 duplicates) of different conspecific numbers rather than by obtaining single numbers with many duplicates. On the former procedure population variation can be effectively assessed, while the latter procedure contributes little.

The reasons for the inadequate documentation of the Papuasian flora can be entirely understood at the most immediate and basic operational level: that of the individual collector laboring in the bush. No matter how much individual effort is expended, the *per capita* outputs are not going to increase to an extent necessary to reverse the current trends in botanical inventory. Since personal yields are not amenable to improvement, the common sense alternative is to expand the workforce. The most practical and socially realistic means of achieving this in traditional societies is through the application of parataxonomists.

An unfortunate fact of contemporary surveys is that parataxonomy-assisted outputs in themselves cannot achieve all the desired objectives. Even when survey collections attain respectable volumes, many past efforts have suffered from the myopic attitude that the botanical gatherings are an end in themselves. Oftentimes there has been no attempt to disseminate findings, or even to assemble the results into any kind of usable form. These omissions discourage rationalization of resource management within the surveyed areas, which in practical terms is probably the most important downstream product from biosurveys.

Perhaps the best example of the preceding circumstance is provided by current developments in the April-Salumei region of East Sepik Province. No other classical locality in Papuasia is of such critical historical-biotic value, owing to the fact that nearly all of Ledermann's interior sites from the 1912-13 Kaiserin-Augusta (Sepik) Expedition fall within this tract (cf. Veldkamp et al. 1988). Although key localities in the Hunstein Range were revisited by CSIRO botanists Hoogland and Craven in 1966, and by a National Geographic sponsored contingent in 1989, there is still no compilation of surviving specimens from the now mostly-destroyed Ledermann sets, nor any published compendium from the subsequent Hunstein expeditions.¹ In the meantime, scores of significant discoveries have been recognized from the newer surveys, including 6 species of *Freycinetia* from the 1989 expedition alone (Huynh 1999). The recovery of the endemic genus *Sepikea*, formerly known only from an illustration in Schlechter (1923), has also occurred in recent years (B.L. Burtt, pers. comm.). These developments go unnoticed by resource planners because the discoveries are reported in technical journals which are inaccessible to government agencies or are discussed only within a small circle of botanical collaborators. The April-Salumei tract is currently a focal point of contention between conservation, landowner, logging, and mining interests (cf. Bakker 1994; Filer & Sekhran 1998), and a variety of future land uses is now under planning consideration. The results of uninformed action in a locality with such unique biotic and scientific-historical values are potentially devastating.

It is thus an imperative that liaising mechanisms be erected for ensuring that surveys connect directly with the agencies responsible for priority-setting

¹There is an unpublished report (Sohmer et al. 1991) but it contains many misidentifications.

in wilderness territories. It is not sufficient to establish links between universities, herbaria, or NGOs with community-level jurisdictions over survey sites. These entities do not possess the statutory powers for determining policies and priorities in the resource operations (e.g., forestry and mining) which have the greatest potential impacts on the environment. Without critical inputs to the planning facilities in government, surveys may end up as mere information-gathering exercises from habitats which subsequently disappear. At a minimum, floristic inventories should be consciously directed to the Forest Planning Division of the PNG Forest Authority, and to the Nature Conservation Division of the Office of Environment and Conservation.

THE RELATIONSHIP TO COMMUNITY AND FLORISTIC PATTERNS

In the last decade, a substantial amount of data has been acquired from many of PNG's forest environments. The greater part of this work has been conducted under the auspices of NGOs operating within their respective conservation areas. A discouraging aspect of many such studies is that they are either never formally published, or otherwise appear in publications of limited readership and distribution. In the following discussion, several distinct but interrelated issues are considered, in some cases drawing upon data which are available locally, but not readily accessible to the wider scientific community. The commentary addresses selected topics in **1)** morphospecies enumeration, **2)** floristic richness on environmental gradients, and **3)** the relationship between collections in Lae Herbarium to timber concessional activity.

1) Morphospecies enumeration.—Although the size of its flora is of considerable general interest, there is little consensus on the number of plant species within Papuasias (cf. Collins et al. 1991; Frodin 1984; Good 1960; Hoft 1992; Johns 1993; Womersley 1978). The only sure way of gauging the total floristic inventory for PNG is through systematic revision, but it will be many generations before a *Flora Malesiana*-style compilation can be concluded (Geesink 1990).

In spite of such concerns, the locality-specific inventories are the most important ones for planning purposes. While flora-wide summaries may be of broad conceptual interest, they do not provide the sort of information which is relevant at operational levels. Management actions are typically evaluated and implemented for specific localities, and this requires detailed information on the floristic profiles of individual tracts. Even if many plant families will remain unrevised through the foreseeable future, the enumeration of Papuasian morphospecies and the determination of their spatial distributions is an achievable objective. Knowledge of the local components of floristic diversity is a basis for rationalized priority-setting and decision-making at the level of agency implementation. And ultimately it is the conservation of local diversity which is the foundation for future floristic inquiry even though the larger regional patterns provide the basis for placing the local knowledge in context.

Species checklists are thus of greater practical significance for planning and conservation than is generally conceded, if they are used in conjunction with other information sources. However, unless the compilations accurately reflect current taxonomy and are periodically reviewed and adjusted, they can be an actual disservice to government planners and managers. In this connection, attempts to automate the process of plant identification through interactive keys have promise as a heuristic and practical tool, although the methodology is likely to be constrained by limited access to computer resources within countries such as PNG.

2. Floristic richness on environmental gradients.—The total number of Papuan plant morphospecies enclosed within individual territories, on elevational or horizontal environmental gradients, is also still unknown. Recent intensive surveys at Crater Mt. have produced the highest single-locality census thus far achieved in PNG (i.e. 1,200 morphospecies: Takeuchi 1999, 2000b) but the counts are not comprehensive. Inventories intending to evaluate total floristic content within environmentally variable tracts must eventually quantify species richness between habitats. A problem for any manager working with limited resources is the question of how to apportion survey effort through time and space to a targeted flora.

In the Neotropics the answer to this issue would be relatively straightforward. The number of tree species is inversely related to elevation, with the highest counts in the lowlands and with richness falling progressively with altitude (Gentry 1988). When the emphasis is on evaluating the tree flora (as is usually the case with forestry operations), surveys would produce maximized returns by concentrating at low elevations. A salient qualification however, is that neotropical richness seems to be highest in the montane zone (cf. Henderson et al. 1991) if all plants (including nontree species) are considered, so the optimal sampling plan for surveys would be dependent on the objectives.

In Papuan habitats floristic richness patterns are more equivocal and complex than those reported by Gentry (1988) and are generally consistent with Henderson et al. (1991) if the nontree component is considered. On New Ireland, tree counts have been reported as declining monotonically with elevation in the manner of the Neotropics (Takeuchi & Wiakabu 1997). However this result has not been replicated and may be an artefact of widely separated sampling stations. Foster (1997), by employing a continuous line sampling methodology, concluded that the species richness curve for New Ireland has a mid-elevation bulge, being highest at 750 m and diminishing above and below that level. Kulanget al. (1997) reported maximum species totals at 1,000 m elevation along an altitudinal sequence in Madang Province. In a similar study, species diversity from forest habitats on New Britain attained maximum values between 600–800 m (Balun et al. 1996). Previously, the 1995 Bismarck-Ramu survey had determined the 600 m level as being floristically richest among examined sites

(Hedemark et al. 1997). Although the lowland-montane ecotone has not been critically evaluated in Papuaasia, there are converging indications that the point of highest floristic development lies somewhere in or near that transition. An obvious implication for local conservation initiatives is that this interval should thus serve as the botanical core for protected areas. Future surveys can increase their efficiency by allocating more time to the low montane ecotone instead of attempting equal coverage of all habitats on an altitudinal gradient. The lowland rainforest and the high montane forests are apparently less diverse, so survey effort should be allocated accordingly.

The substantial variation (600–1,000 m) in the elevations of beta diversity maxima suggests influence of local factors. From the differences between sites it is also apparent that the richest communities can be identified only by actual survey, and not by extrapolation from results obtained in other areas. Site-specific vegetational histories, climatic considerations including *Massernerhebung* (cf. Grubb & Stevens 1985), substrate distinctions, sampling methodology, etc., are factors probably responsible for the contrasts between locations.

Even while the argument from raw numbers seems clear enough, the situation is still obscured by considerations of quality. Plant species do not have the same value, at least from conservation perspectives. The local endemic is understandably valued more than widely distributed taxa, so richness is only one aspect of site assessment. Due to difficulties in generating the required data, there are no published accounts comparing endemism between different Papuan environments. This is an obvious lacuna which should be considered in future inventories. Although the unrevised status of many plant families is a serious constraint, preliminary estimates could be obtained by using the taxa covered in modern treatments.

It is also appropriate to note that while previous efforts have attempted to quantify relationships between beta diversity and elevation, the critical variable is not elevation but the forest classification unit. In whatever manner the forest/community type is defined, whether by species composition, physiognomy, or a combination of both, it is really the forest type which underpins the richness variation. Elevation is an obvious environmental control but its effects are manifested through the vegetation formation or 'life zone,' and it is certainly not the only controlling factor. Knowing which forest formations have the highest number of species, in both absolute and proportional terms, is thus a more meaningful focus for inquiry than any site-specific relationship between richness and elevation *per se*. This is especially true because the same species and/or vegetation types often have different elevational ranges at different locations, which is at least partly responsible for the inconsistent results obtained by current investigations on elevation-dependent richness. On anecdotal grounds, it is apparent for example, that many plant taxa have anomalous low-elevational occurrences

on ultrabasics. There are also the *Massernerhebung* induced permutations, to cite another obvious influence (cf. the 'melange effect' in Grubb & Stevens 1985).

Establishing correlations between forest units and floristic diversity is complicated by the existence of several contrasting systems for forest classification in Papuasia (i.e., Hammermaster & Saunders 1995; Johns 1977; Paijmans 1975, 1976; Saunders 1993). The first scheme however, is now supported by a GIS (Geographic Information System) augmented by transparency overlays for the pre-existing 1:500,000 scale topographic maps (Australian Survey Corps) and also with separately issued 1:100,000 scale maps showing the various forest units for all of PNG. It thus provides a very useful foundation for planning and executing the surveys needed to resolve outstanding issues.

3. The relationship between collections in Lae Herbarium to timber concessional activity.—Recent summaries (Balgoo et al. 1996; Welzen 1997) from the *Flora Malesiana* suggest that New Guinea has the highest rates of floristic endemism in Malesia. Based on current revisions, most of the endemic species appear to be concentrated in montane habitats. Using selected genera, Heads (in press) arrives at some of the same conclusions regarding relationships between montane environments and endemism.

Collection densities in Papuasia are very clearly skewed in favor of montane areas (Conn 1994), so to a certain extent phytogeographic summaries will be affected by the sampling inequalities. The greater part of the LAE holdings (and thus the overseas duplicates resulting from them) originate from the Mamose² region and the Highlands (cf. Fig. 1), so it is inevitable that a certain bias has been introduced into distributional summaries derived from such a foundation. The magnitude of such biases can be inferred from the geographical unevenness of collections in the Lae Herbarium, as summarized in Table 1.

The core of the PNG national collections in botany consists of the NGF and LAE series specimens (1–49,999 on the New Guinea Force numeration and thereafter with higher numbers on the LAE sequence). The institutional sets currently end at ca. 85,000. Both the NGF and LAE sequences have many blank intervals consisting of number blocks which were assigned to past collectors but never actually used. A substantial amount of material was also rejected or destroyed after the collections had been recorded. Back-numbering of contemporary gatherings has been employed in an attempt to fill in these gaps but there are still much fewer collections than indicated by the institutional number. Table 1 is thus based on a manual count of archived labels physically represented by corresponding specimens in the herbarium.

The NGF and LAE series constitute approximately 25% of the estimated 275,000–300,000 specimens in the national herbarium, though it should be

²Mamose region is the administrative unit composed of West Sepik, East Sepik, Madang, and Morobe Provinces.

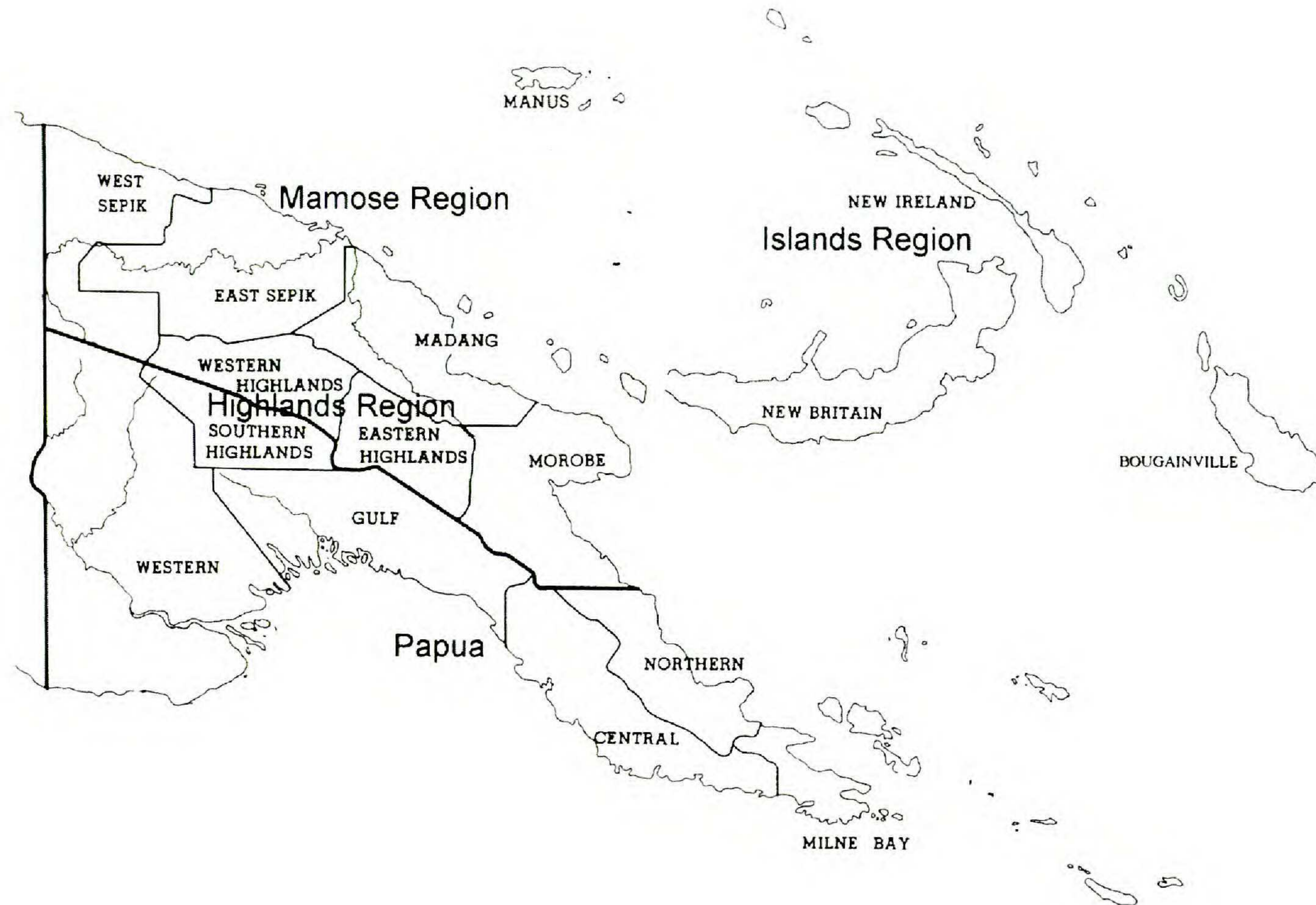


FIG. 1. Provinces of Papua New Guinea. The Western Highlands are composed of Enga in the western half and Western Highlands Province s. str. in the eastern part. In similar fashion the Eastern Highlands are divided respectively into Chimbu (Simbu) and Eastern Highlands Province s. str. The Southern Highlands have geological affinities to the Australian craton rather than to the Island Arc terranes (Pigram & Davies 1987).

TABLE 1. Representative profile of plant collections at Lae Herbarium tabulated by province and region of origin (from NGF, LAE, and CSIRO series numbers).

Province	Counts	% of Total Sample
HIGHLANDS REGION		
Chimbu	8,060	8.86
Eastern Highlands	5,837	6.42
Enga	38	0.04
Western Highlands	3,844	4.23
Subtotal Highlands Region	17,779	19.6
ISLANDS REGION		
East New Britain	1,701	1.87
Manus	896	0.98
New Ireland	1,418	1.56
North Solomons (Bougainville)	2,475	2.72
West New Britain	4,104	4.51
Subtotal Islands Region	10,594	11.6
MAMOSE REGION		
East Sepik	3,396	3.73
Madang	3,485	3.83
Morobe	25,509	28.04
West Sepik	6,082	6.69
Subtotal Mamose Region	38,472	42.3
PAPUAN REGION		
Central	8,262	9.08
Milne Bay	5,404	5.94
Northern	1,520	1.67
Subtotal Papuan Peninsula	15,186	16.7
Gulf	1,666	1.83
Western	3,691	4.06
Southern Highlands	3,569	3.92
Subtotal Papuan Austrocraton	8,926	9.8
Total	90,957	100.0

noted that the size of the total holdings is not accurately known and tends to be overstated because of discontinuities in the recording system. A major data recovery effort would be required to collate locality information on most of the remaining collections. The notable exceptions are the early CSIRO sets obtained by L. Craven, T. Hartley, P. Heyligers, R. Hoogland, K. Paijmans, and R. Schodde. The LAE duplicates by these collectors are entered in herbarium logbooks and have been easily incorporated into Table 1. Approximately 91,000 specimen numbers are included in the combined tallies (Table 1).

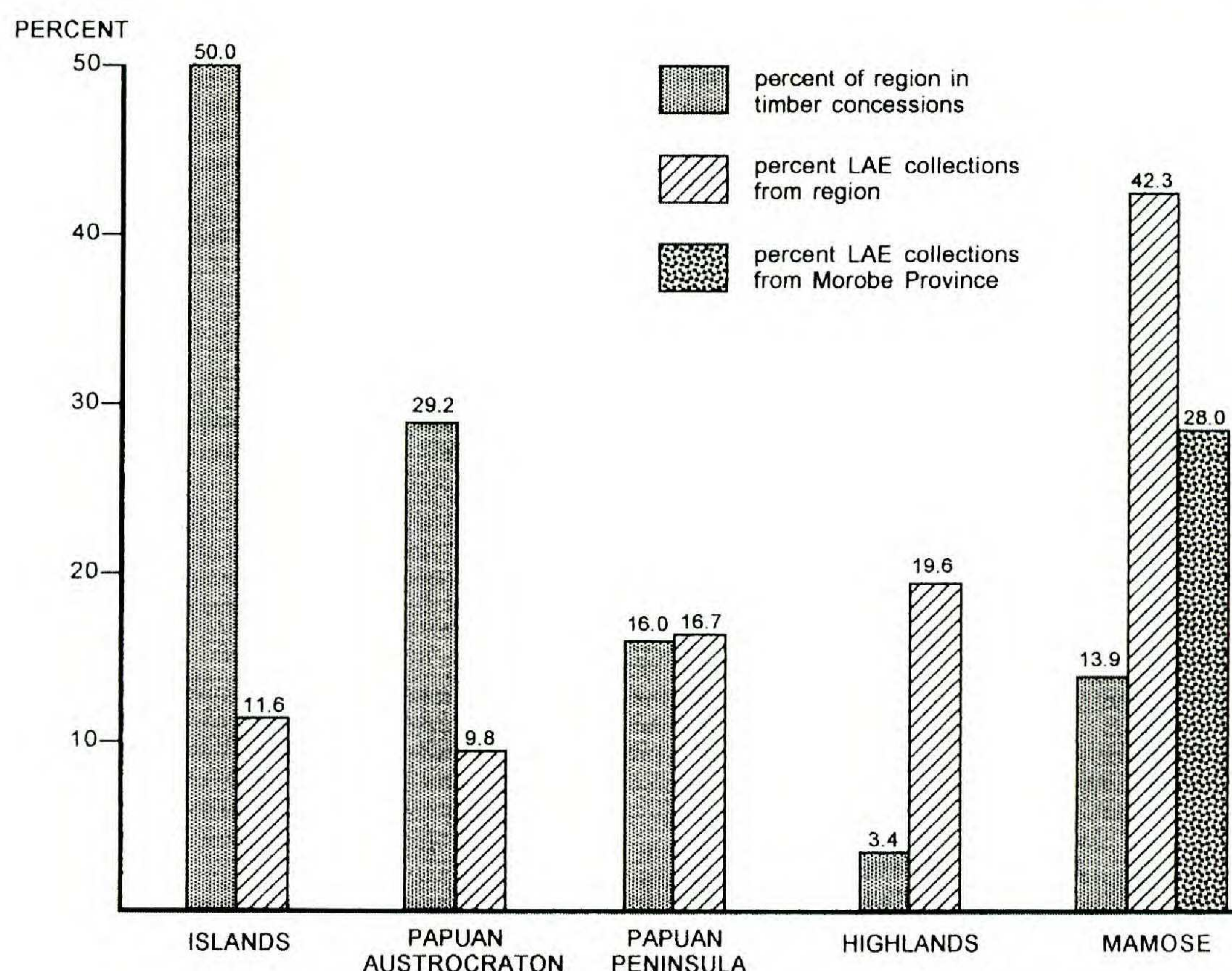


FIG. 2. Relationship between contemporary logging intensity and the relative distribution of historical LAE collections. The percentage of specimens from Morobe Province is shown as a separate bar next to the cumulative percentage for Mamose region. In general, the highest proportion of timber concessions are in areas with the least botanical documentation, thus severely constraining forest planning and management.

The obvious preponderance of specimens from Morobe and adjacent provinces, and the opposing paucity of material from Western and Gulf, are apparent even from casual inspection of the national collections. With 28% of the collections, Morobe Province is very disproportionately represented. The disparities clearly reflect the concentration of Forest Service facilities and infrastructure at Lae and Bulolo. A similar situation is shown by the relatively high numbers of specimens from Central Province, especially from the Brown River and the Sogeri areas, owing to their proximity to Port Moresby.

If timber concessions are tabulated by province and region (Table 2), a general inverse relationship is evident between the distribution of existing concessions and the collections coverage of the corresponding areas (Fig. 2). The provinces most susceptible to logging impacts (Islands region and the Austro-geoprovince) have the fewest herbarium specimens as reflected in the LAE sample, while the best documented regions (Mamose and Highlands) have relatively little logging activity. This inverse relationship shows that future forest sector development is likely to be most intense in areas which are floristically the least known, and

TABLE 2. Summary of timber concessional areas in Papua New Guinea tabulated by province and region.

Province	Total Concessional Area (ha)	% of Province in Concessions
HIGHLANDS REGION		
Chimbu	0	0.0%
Eastern Highlands	0	0.0%
Enga	43,483	3.7%
Western Highlands	83,129	9.8%
Subtotal Highlands Region	126,612	3.4%
ISLANDS REGION		
East New Britain	577,287	38.2%
Manus	51,734	24.6%
New Ireland	564,631	58.7%
North Solomons (Bougainville)	101,120	10.8%
West New Britain	1,552,628	74.8%
Subtotal Islands Region	2,847,400	50.0%
MAMOSE REGION		
East Sepik	630,949	14.4%
Madang	387,870	13.5%
Morobe	276,751	8.2%
West Sepik	681,255	18.9%
Subtotal Mamose Region	1,976,825	13.9%
PAPUAN REGION		
Central	484,778	16.2%
Milne Bay	225,101	15.8%
Northern	358,096	15.9%
Subtotal Papuan Peninsula	1,067,975	16.0%
Gulf	2,536,478	74.9%
Southern Highlands	39,241	1.5%
Western	2,028,312	20.7%
Subtotal Papuan Austrocraton	4,604,031	29.2%

may thus involve considerable biodiversity risk.

Documentation action is especially imperative for localities where concessional activity is currently occurring or imminent (cf. Fig. 3, reproduced from Papua New Guinea Forest Authority 1998). Floristic data is required not only to rationalize the logging plans for affected areas, but also to assess the postharvest consequences of forest felling. The opportunity for discovering localized species and of recording populational variation could be otherwise irretrievably lost.

Judging from historical patterns of collecting and future forestry needs, the highest-priority documentation targets should be the lowlands of Papua and the

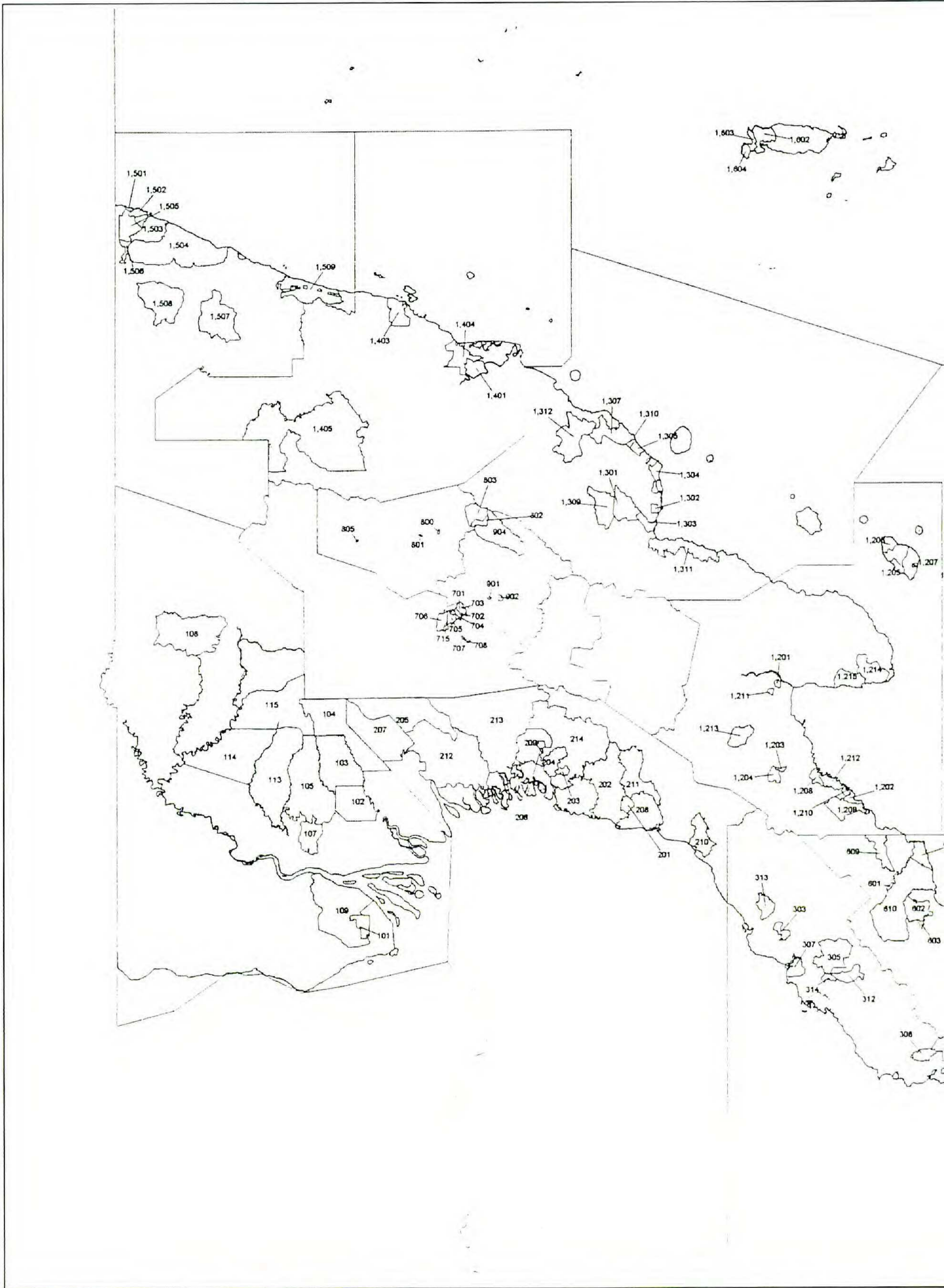
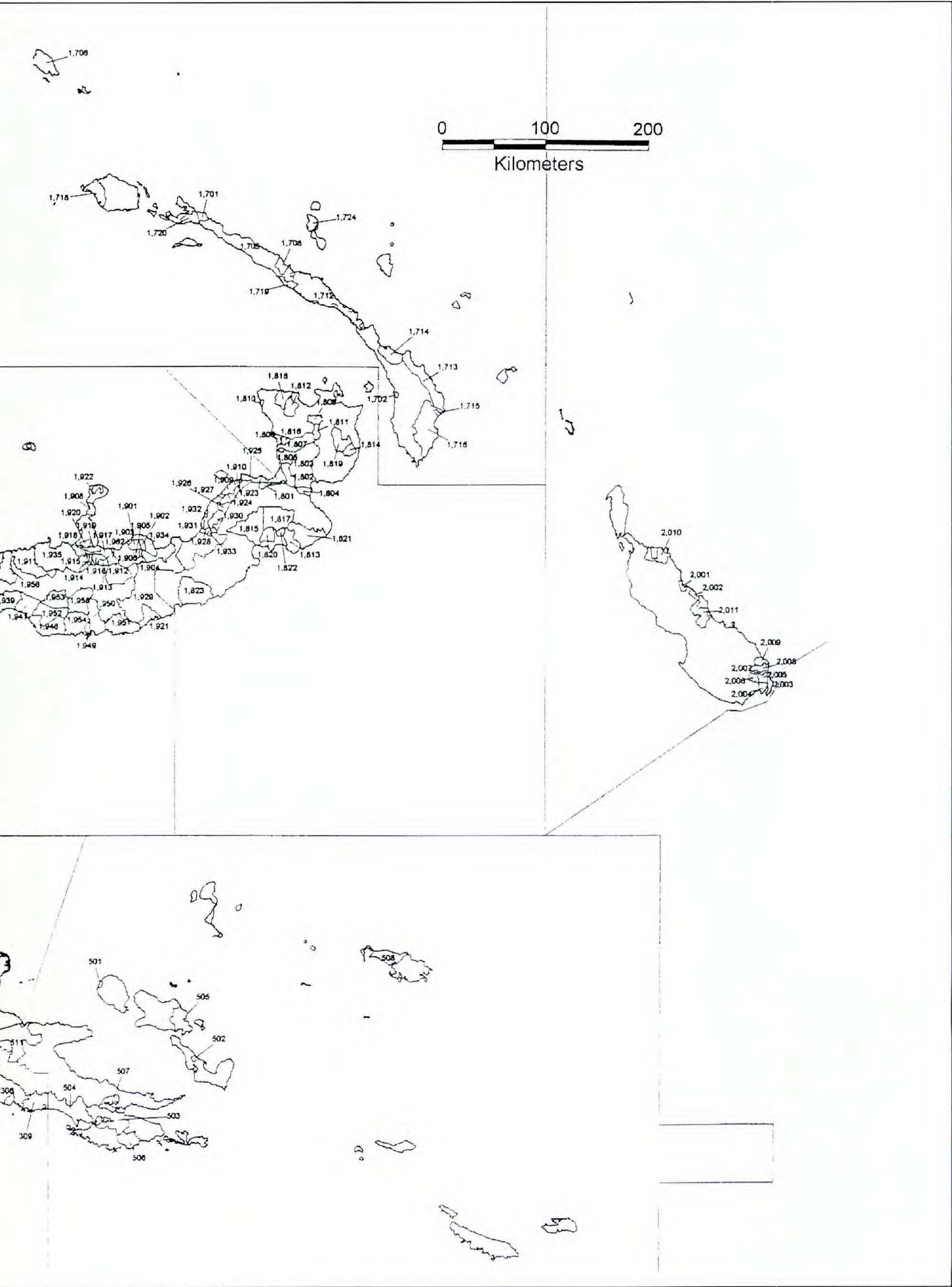


FIG. 3. Map of the timber concessions in Papua New Guinea.



Austrocraton subregion, particularly Gulf Province. This does not necessarily mean that such environments are more speciose or significant, only that the flora there is comparatively less explored and at greater risk of alteration before it has been documented. Based on Fig. 3, New Britain should also be a priority target, but much of the island has been previously logged and taxonomic losses have presumably already occurred as a result of forest removal (oil palm plantations now cover large sections of West New Britain). In contrast, Gulf environments are primarily in natural growth.

DISCUSSION

Papuan bioinventories involving expeditions and contingents of highly trained specialists are relicts from a bygone era. Institutional and social realities within a rapidly evolving PNG indicate the appropriateness for change, even though the manifestations of such need are obscured by the misconceptions imposed by international and cultural distance. Existing failures in documentation are certainly not attributable to a lack of collective scientific interest or dedication of past workers. The deficiencies are principally methodological. The evidence of the last 100 years shows that conventional itineraries are not going to achieve adequate collections saturation of critical environments within acceptable time frames. As long as the burdens of inventory are borne primarily by an elite professional corps, the documentation of PNG's biotic richness will continue to be an elusive objective. The human assets for survey must be applied in more effective ways than previous programs or the deficiencies will persist. Unfortunately time is running out.

Past attempts at floristic inventory have been institutionally centralized, expeditionary, brief, logistically intensive, and with participation by a select membership. Future operations will need to become decentralized, continuous, participatory, and effected primarily by personnel that are preferably actually living at the sites being subjected to bioevaluation. Parataxonomists and the infrastructure to support them, are necessary elements in achieving such outcomes. The new schedules will also have to be acutely responsive to emerging grassroots assertion of community ownership rights and the resulting demands for stakeholder participation in all activities involving customary resources. Unless there is a major rethinking and overhaul of existing strategies, the objectives outlined by van Steenis half a century ago are unlikely to be realized.

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